

**REMARKS**

Entry of the foregoing, re-examination and reconsideration of the subject matter identified in caption, as amended, pursuant to and consistent with 37 C.F.R. § 1.111, and in light of the remarks which follow, are respectfully requested.

Claims 8-10 have been amended to replace the expression "the thermoplastic elastomer" with --the thermoplastic elastomer (A)--. No new matter has been added.

Upon entry of the Amendment, claims 1-42 will be all the claims pending in the application.

**I. Response to Claim Objection**

Claims 8-10 were objected to for informalities. Applicants respectfully submit that the claims as amended do not contain informalities.

As noted above, claims 8-10 have been amended to adopt the language "the thermoplastic elastomer (A)," as suggested by the Examiner. Accordingly, the Examiner is respectfully requested to reconsider and withdraw the objection.

**II. Response to Rejection under 35 U.S.C. § 102(b)**

Claims 1-15 and 29-33 were rejected under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 6,191,210 to Rosch et al. Applicants respectfully traverse the rejection for the following reasons.

Independent claim 1 recites a solvent dispersion of a composite resin, which comprises a solvent and a composite resin comprising a thermoplastic elastomer (A) and a polymer of copolymerizable monomers (B) comprising a monomer having an  $\alpha,\beta$ -monoethylenically unsaturated group and other copolymerizable monomer(s), wherein the thermoplastic elastomer (A) is a propylene-based elastomer having a molecular weight distribution ( $M_w/M_n$ ) of 3 or less

as measured by gel permeation chromatography (GPC), and the copolymerizable monomers (B) include at least one monomer containing no functional groups.

By using the propylene-based elastomer having a molecular weight distribution (Mw/Mn) of not more than 3, there can be provided a coating material, a primer, an adhesive, an additive, a binder, a film, and a primer for strippable paints and traffic paints, which can be applied by spray coating as the resin solution does not undergo separation; which show no film surface tackiness when applied to form a coating film; and which result in a coating film obtained by using a curing agent having an isocyanate group in the molecule. The resultant coating film exhibits superior weather resistance as compared with coating films of polyolefins modified by chlorination. In addition, the resultant coating films can exhibit excellent adhesiveness to untreated polyolefinic resin films, sheets or molded products. Furthermore; the resultant coating films can have excellent heat-sealability at low temperatures (see page 5, line 17 to page 6, line 5 of the present specification). These effects are also demonstrated by the comparison between Examples and Comparative Examples in the specification.

The Office Action asserts that "the molecular weight distribution for the high-conversion free radical polymerization [in Rosch et al.] is in the range of 2-5" (page 5, 1st paragraph of the Office Action). Applicants respectfully disagree.

Applicants advise that a molecular weight distribution (Mw/Mn) of a typical polyolefin is not less than 3. See, e.g., Furumiya et al., *Relationship between molecular characteristics and physical properties of linear low density polyethylenes*, Pure & Appl. Chem., Vol. 57, No. 6, pp. 823-832 (1985); and Komatsu et al., *Novel polymer with metallocene catalyst*, Chapter 4 (with partial English translation), 1999. For the Examiner's convenience, copies of these two documents are attached hereto. That is to say, a propylene-based elastomer having a molecular weight distribution (Mw/Mn) of not more than 3, which is used in the presently claimed invention, is less common.

Rosch et al. discloses a radical polymerization of mixture (A) comprising (meth)acrylic acid monomer (a1) and polyolefin (B) (halogen-free copolymer), which is proceeded by heating under ordinary pressure. However, Rosch et al. does not describe a synthesis of polyolefin (B) itself. In general, the synthesis of polyolefin is performed under pressure and the resulting polyolefin has a molecular weight distribution (Mw/Mn) of not less than 3.

On the other hand, as noted above, the propylene-based elastomer used in the presently claimed invention has a molecular weight distribution (Mw/Mn) of not more than 3, and is not a polyolefin obtained by the common method described above.

Rosch et al. neither discloses nor teaches a polyolefin having a molecular weight distribution (Mw/Mn) of not more than 3, or the above noted effects thereof.

In view of the foregoing, Applicants respectfully submit that claim 1 and dependent claims 2-15 and 29-33 are novel and patentable over Rosch et al., and thus the rejection should be withdrawn.

### III. Conclusion

From the foregoing, further and favorable action in the form of a Notice of Allowance is believed to be next in order and such action is earnestly solicited. If there are any questions concerning this paper or the application in general, the Examiner is invited to telephone the undersigned at his earliest convenience.

Respectfully submitted,

BUCHANAN INGERSOLL & ROONEY PC

Date: March 8, 2010

By: \_\_\_\_\_



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MACROMOLECULAR DIVISION

COMMISSION ON POLYMER CHARACTERIZATION  
AND PROPERTIES

WORKING PARTY ON STRUCTURE AND PROPERTIES  
OF COMMERCIAL POLYMERS\*

RELATIONSHIP BETWEEN MOLECULAR  
CHARACTERISTICS AND PHYSICAL  
PROPERTIES OF LINEAR LOW  
DENSITY POLYETHYLENES

*Prepared for publication by*

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## Relationship between molecular characteristics and physical properties of linear low density polyethylenes

**Abstract** - The relationship between molecular characteristics and physical properties of linear low density polyethylenes (LLDPE) was investigated in comparison with low density polyethylenes produced by high pressure processes (HP-LDPE). Differences in molecular characteristics, such as branching structure, spherulite structure and solution properties between LLDPE and HP-LDPE were made clear. A comparison of both polymer films in an impact strength and heat resistance was made. The higher Vicat softening point of LLDPE compared with HP-LDPE could be attributed to the thicker lamella of LLDPE than that of HP-LDPE because of the difference of the branching structures. Some comparisons of LLDPE with HP-LDPE on rheological properties and processability parameters were tried. There are apparent differences between both polymers in the dynamic viscoelastic properties and the extensional viscosity development. The melt flow rate value, which is widely used as a processability parameter, of LLDPE is more than one decade lower than that of HP-LDPE at a given molecular weight because of the difference of the molecular dimension. The melt tension, which is another processability parameter widely used, of LLDPE is lower than that of HP-LDPE at a given melt flow rate. The melt tension data also suggest that the melt tensional properties and processability are mostly governed by a nonlinear extensional properties of the melts in a long time scale.

### INTRODUCTION

The manufacturing method of low density polyethylenes by radical polymerization under conditions of high temperature and pressure ( $200 \sim 280^\circ\text{C}$ ,  $1000 \sim 3000 \text{ Kg/cm}^2$ ) was found by Imperial Chemical Industries in 1933. Later on, a new method for manufacturing low density polyethylenes by copolymerization of ethylene and  $\alpha$ -olefins with Ziegler catalysts (Ti-catalyst systems) or Phillips catalysts (Cr-catalyst systems) under moderate conditions of temperature and pressure ( $60 \sim 200^\circ\text{C}$ ,  $5 \sim 200 \text{ Kg/cm}^2$ ) was developed. This method for manufacturing linear low density polyethylenes (LLDPE) by copolymerization of ethylene and  $\alpha$ -olefins has suddenly appeared before the footlights since several grades of LLDPE by gas-phase polymerization were commercialized by Union Carbide Corporation in 1977. However, Du Pont Canada and Mitsui Petrochemical Industries had already succeeded in the commercialization of the same type of polymers by solution polymerization processes which were developed by themselves in 1960 and 1972, respectively. Especially, Mitsui Petrochemical Industries has been manufacturing LLDPE by the solution polymerization process having no section for removing catalyst residue by applying its own developed Ti-catalyst system of high activity.

Although LLDPE thus developed has been replacing high-pressure low-density polyethylenes (HP-LDPE) in various fields of the market, quite a few academic reports on structures and/or properties of LLDPE commercially manufactured have been published (ref. 1,2). The Sub-Group meeting in Japan of IUPAC Working Party IV-2-1 has worked to investigate the relationship between molecular characteristics and physical properties of commercially manufactured LLDPE in comparison with HP-LDPE and high density polyethylenes (HDPE). This report describes the result of the experiments and discussions which have been made by the Sub-Group for these two years. Molecular characteristics of LLDPE are given in the third section. In the fourth and fifth sections, mechanical and thermal properties and rheological properties of LLDPE are discussed in relation to molecular characteristics, respectively. We believe that these studies incorporated herein would be very useful for the accurate understanding of the qualities of LLDPE which will be more prevalent in the future.

### MATERIALS

Linear low density polyethylenes (LLDPE) employed in this report are commercially available

ones which were manufactured by solution polymerization processes of Mitsui Petrochemical (Neo-zax, Ultzax) and Dow Chemical (Dowlex). Other types of polyethylenes (HDPE, HP-LDPE), polybutene-1 and polyoctene-1 were also used for comparisons. These polymers were commercially manufactured except polyoctene-1 which was prepared in the laboratory scale. The weight-average molecular weights  $M_w$ , the molecular weight distributions  $M_w/M_n$ , the densities and the manufacturers (trade names) are given in Table 1.

TABLE 1. Molecular characteristics of polymers employed

Resin	$M_w \times 10^{-5}$	$M_w/M_n$	$d$ g/cm <sup>3</sup>	Resin manufacturer (Trade name)
HDPE	5 ~ 15	5 ~ 7	0.955 ~ 0.968	Mitsui Petrochemical (Hi-zax)
LLDPE	5 ~ 20	3 ~ 7	0.920 ~ 0.945	Mitsui Petrochemical (Neo-zax, Ultzax) Dow Chemical (Dowlex)
HP-LDPE	18 ~ 31	6 ~ 10	0.920 ~ 0.929	Mitsui Petrochemical (Mirason)
Polybutene-1	100	7	0.915	Shell Chemical
Polyoctene-1	10	6	—	(Shell Polybutylene) (experimental resin)

The Sub-Group IV-2-1-2 (Eastern Europe, Chairman: Dr. Stejskal) kindly cooperated in determining  $M_w$  of our LLDPE samples (3 samples) by a light scattering method. Unfortunately, there was difference between their data measured in diphenylmethane solutions and ours in 1-chloronaphthalene. Accordingly, we could not adopt their data in this report to our regret.

#### CHARACTERISTIC STRUCTURES AND PROPERTIES OF LINEAR LOW DENSITY POLYETHYLENES

LLDPE is different from HP-LDPE in the molecular structure, such as branching structure, molecular weight distribution and chemical composition distribution, and also in higher order structure, such as crystalline/amorphous structure and spherulite structure. In this section, the characteristic structures and the solution properties of LLDPE are described in comparison with HP-LDPE and a few other polyolefins.

##### Branching structure and density

HP-LDPE manufactured by conventional radical polymerization has long-chain branchings mainly. On the other hand, LLDPE is a linear polymer with short-chain branchings originated from  $\alpha$ -olefin used as a comonomer. Figure 1 shows that the density of LLDPE decreases as the comonomer content in a chain increases. The density of ethylene/4-methylpentene-1 copolymer decreases more rapidly with the comonomer content than ethylene/butene-1 copolymer does. The reason would be that 4-methylpentene-1 is not incorporated into the crystal lattice, while butene-1 is easily incorporated into the crystal lattice (ref. 3).

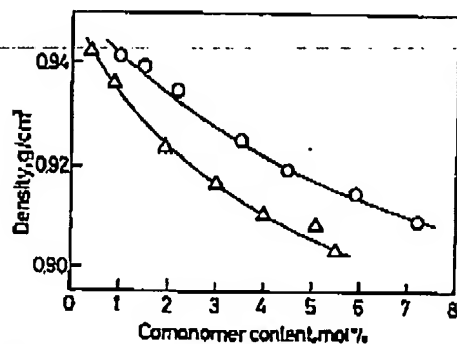


Fig. 1. Density vs. comonomer content correlation for LLDPE: Open circles and triangles denote for the values for ethylene/butene-1 copolymers and ethylene/4-methylpentene-1 copolymers, respectively.

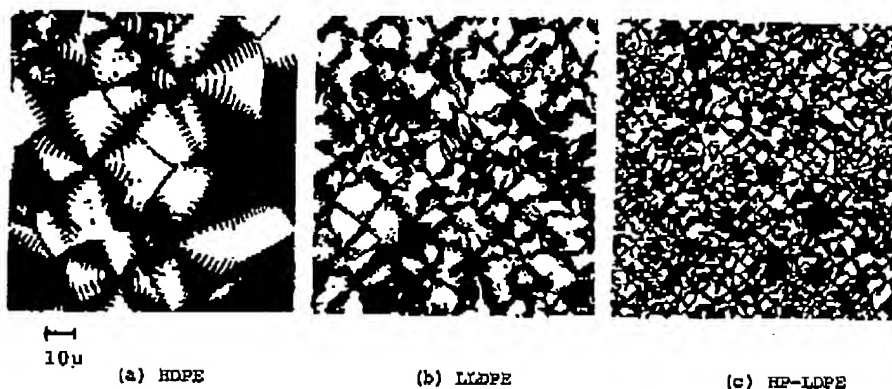


Fig. 2. Spherulite structures of polyethylenes: (a);  $d=0.968$ , (b);  $d=0.920$  (c);  $d=0.929$

#### Spherulite structure

Figure 2 shows spherulite structures of HDPE, LLDPE and HP-LDPE. The differences among them are fairly clear. HDPE has the well-grown spherulite structure. On the other hand, LLDPE has the small and indistinct spherulite structure because the short-chain branchings hinder the crystallization and the formation of spherulite. This is more remarkable in the case of HP-LDPE having long-chain branchings. These facts show that the shape and size of spherulites of the polyethylenes are strongly dependent on the length and frequency of branching in the molecules.

#### Solution property

The whole polymers of HDPE, LLDPE and HP-LDPE were fractionated by a column fractionation method. Then, the weight-average molecular weights  $M_w$  of the fractions were measured by a light scattering method in 1-chloronaphthalene at 135°C. The intrinsic viscosities  $[\eta]$  were measured in decalin at 135°C. Relations between  $M_w$  and  $[\eta]$  for different series of polyethylenes are shown in Fig. 3.  $[\eta]$  of LLDPE is almost equal to that of HDPE at a same  $M_w$ , but higher than that of HP-LDPE. This result well corresponds to that obtained through the comparison between HDPE and HP-LDPE by Tremantozzi (ref. 4). The result shown in Fig. 3 suggests that the molecular dimension in decalin solution for HP-LDPE having long-chain branchings is smaller than that for linear polyethylenes of the same  $M_w$ . In the case of HP-LDPE, the higher the molecular weight becomes, the more easily the long-chain branchings are formed because of the increasing opportunity of chain transfer from polymer radicals to polymer chains during polymerization. This is the reason why the slope of  $[\eta]$  vs.  $M_w$  curve for HP-LDPE decreases in the high  $M_w$  region as is seen in Fig. 3. Molecular dimension of polymer chain having many long branchings is much smaller than that of linear counterpart with the same molecular weight. The schematic representations of LLDPE and HP-LDPE chains in good solvent are illustrated in Fig. 4.

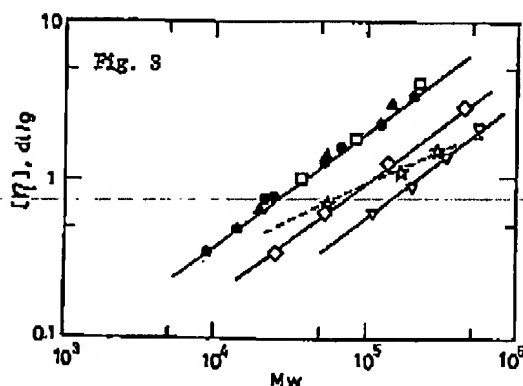


Fig. 3. Intrinsic viscosity  $[\eta]$  vs. weight-average molecular weight  $M_w$  correlation for fractionated polymers:  $\square$ ; HDPE ( $d=0.960$ ),  $\bullet$ ; ethylene/butane-1 copolymer ( $d=0.935$ ),  $\Delta$ ; ethylene/octene-1 copolymer ( $d=0.929$ ),  $\star$ ; HP-LDPE ( $d=0.929$ ),  $\diamond$ ; polybutene-1,  $\nabla$ ; polyoctene-1.  $M_w$  of fractions were measured in 1-chloronaphthalene at 135°C and  $[\eta]$  of fractions were measured in decalin at 135°C.

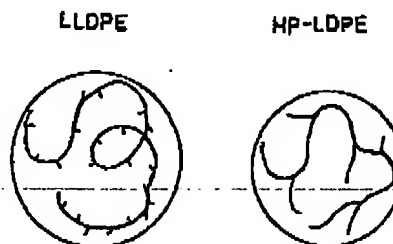


Fig. 4

Fig. 4. Schematic representations of LLDPE and HP-LDPE chains in good solvent.

Figure 3 also shows the relations between  $M_w$  and  $[\eta]$  for fractions of polybutene-1 and polyoctene-1, in which ethyl and hexyl branchings are alternately connected to carbons of main chains, respectively. Two straight lines drawn on the  $[\eta]$  data for both polymers are parallel to those for HDPE and LLDPE.  $[\eta]$  values for the series of linear polyolefins seem to depend on the length of main chain. In Fig. 5,  $[\eta]$  values of the four series of polyolefins (HDPE, LLDPE, polybutene-1 and polyoctene-1) are plotted against the weight-average molecular weights of main chains  $M_w'$ . For polybutene-1 and polyoctene-1,  $M_w' = (1/2)M_w$  and  $=(1/4)M_w$ , respectively. It is apparent from this figure that linear polyolefins with the same main chain length have approximately the same molecular dimension in good solvent, regardless of length of short-chain branchings. Taking a good look at the figure, the data points for polybutene-1 and polyoctene-1 are located a little lower than those for the linear polyethylenes. The reasonable explanation for this difference has not come out yet.

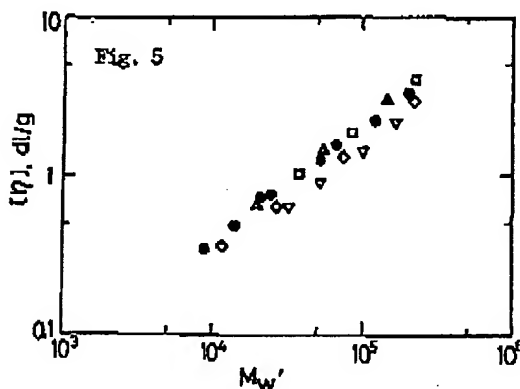


Fig. 5. Intrinsic viscosity  $[\eta]$  vs. weight-average molecular weight of main chain  $M_w'$  correlation for fractionated polymers. Symbols are the same as in Fig. 3.

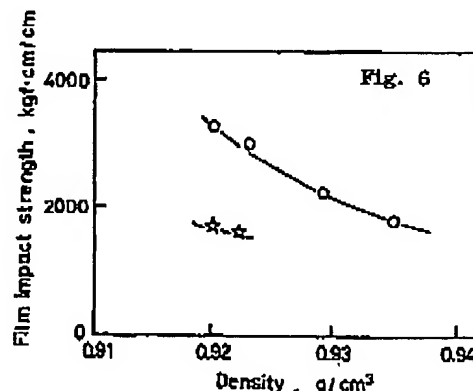


Fig. 6. Impact strength vs. density correlation for LLDPE and HP-LDPE films: Open circles and stars denote the values for LLDPE (MFR=2.3) and HP-LDPE (MFR=2.3), respectively. Tubular films were tested at room temperature.

#### MECHANICAL AND THERMAL PROPERTIES OF LINEAR LOW DENSITY POLYETHYLENE FILMS

As was seen in the preceding section, molecular characteristics of LLDPE are different from those of HP-LDPE in spite of similar density of both polyethylenes. Accordingly, it is very important that the physical properties of both polymers of the same density are compared with each other and differences are made clear. In this section, such a comparison of both polymer films in an impact strength and heat resistance have been made.

##### Impact strength

One of the physical properties of LLDPE film superior to that of HP-LDPE film is the extremely high impact strength. The film impact strengths of LLDPE and HP-LDPE measured by the film impact tester (Toyoseiki Co.) at room temperature are plotted against the density in Fig. 6. Tested samples are 30  $\mu$ m thick and of similar melt flow rate (MFR). As is shown in this figure, LLDPE film gives about two times higher impact strength than HP-LDPE film at the same density.

As a major factor to improve the impact strength, the existence of impact relieving portion is conceivable. The storage modulus  $E'$  and loss modulus  $E''$  of two LLDPEs and HP-LDPE were measured by Rheovibron-II at 110Hz. No difference in the viscoelastic properties was recognized among them as shown in Fig. 7. Then, electron microscopic investigation of the fracture portions of polyethylene films at room temperature revealed that ductile fractures developed mainly. In fact, Fig. 8 which exhibits the result of high speed tensile test (tensile speed is 1000mm/min), clearly shows the much higher tensile strength and elongation for LLDPE film than for HP-LDPE film.

Considering this experimental results from the view point of higher order structure, there presumably exist more tie molecules connecting the lamella of LLDPE having long main chain than HP-LDPE having short main chain due to long-chain branchings. Consequently, LLDPE shows the higher toughness (the total energy absorbed to the break point) and the higher impact strength than HP-LDPE.



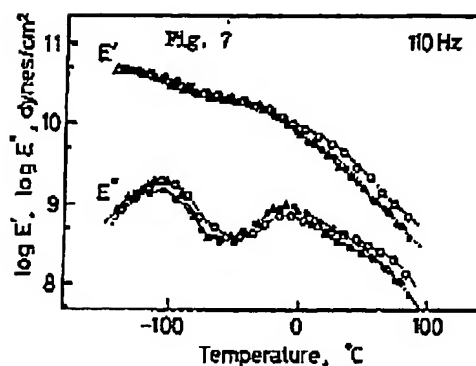


Fig. 7. Storage modulus ( $E'$ ) and loss modulus ( $E''$ ) of polyethylenes as a function of temperature at 110 Hz. Open circles, triangles and closed circles denote the values for ethylene/butene-1 copolymer ( $d=0.935$ , MFR=1.6), ethylene/4-methylpentene-1 copolymer ( $d=0.920$ , MFR=2.1) and HP-LDPE ( $d=0.921$ , MFR=2.9), respectively.  $E'$  and  $E''$  were measured by Rheovibron-II.

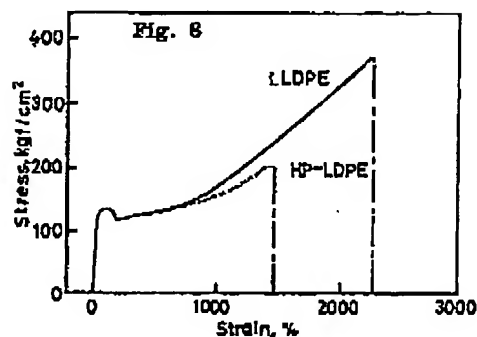


Fig. 8. Stress-strain curves for LLDPE ( $d=0.920$ , MFR=2.1) and HP-LDPE ( $d=0.921$ , MFR=2.9). Tensile speed is 1000 mm/min.

#### Heat resistance

As a yard-stick for judging the use-limitation at high temperatures, the Vicat softening point is generally used. As is understood from Fig. 9, LLDPE has the Vicat softening point about 10°C higher than HP-LDPE of the same density, suggesting that LLDPE is superior to HP-LDPE in terms of the heat resistance. The data for HDPE are located on the extension of those for LLDPE.

Figure 10 shows DSC melting behavior of LLDPE and HP-LDPE of almost the same density ( $d=0.920$  and  $0.921$ , respectively). HP-LDPE gives a broad pattern of melting with the peak at 107°C. On the other hand, LLDPE shows three peaks in the DSC melting endotherm at 106, 119, 123°C. Considering the fact that each fraction of LLDPE by chemical composition shows a respective single peak, the overlapping pattern of DSC for LLDPE would be due to the chemical composition distribution.

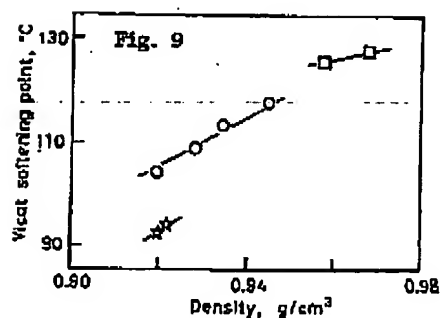


Fig. 9. Vicat softening point vs. density correlation for polyethylenes. Squares, open circles and stars denote the values for HDPE (MFR=5~10), LLDPE (MFR=0.2~4) and HP-LDPE (MFR=2~3), respectively.

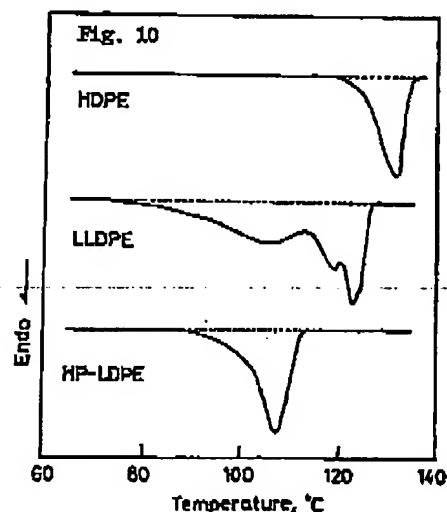


Fig. 10. DSC curves for polyethylenes: HDPE (MFR=5,  $d=0.968$ ), LLDPE (MFR=2,  $d=0.920$ ), HP-LDPE (MFR=3,  $d=0.921$ ). Data were taken with DSC-II (Perkin-Elmer).

A good correlation between the melting point determined by DSC and the lamella thickness measured by a Raman spectroscopic method for HP-LDPE and fractionated LLDPE is shown in Fig. 11. In this figure, a (LLDPE) and b (HP-LDPE) are of approximately the same density, i.e.  $\delta = 0.920 \sim 0.921$ . It is conceived that the lamella of HP-LDPE can not grow thick due to the existence of the long-chain branchings. On the other hand, the thick lamella of LLDPE is resulted from that the linear structure affects positively the formation of perfect lamella. Accordingly, the higher melting point of LLDPE than HP-LDPE of the same density would be attributed to the thicker lamella of LLDPE than HP-LDPE because of the difference of the branching structures.

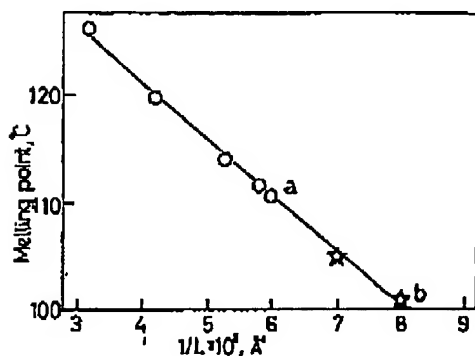


Fig. 11

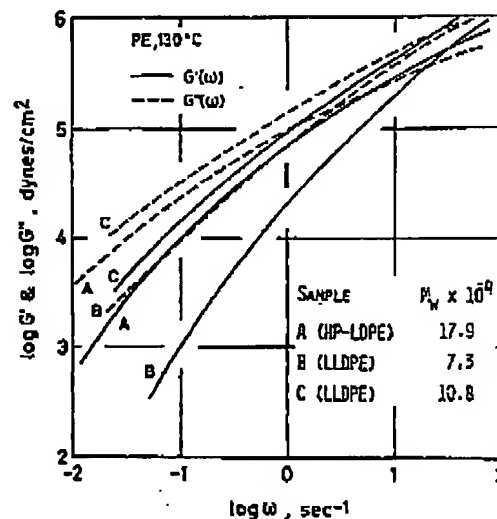


Fig. 12 →

Fig. 11. Melting point vs. lamella thickness ( $L$ ) correlation for HP-LDPE and fractionated LLDPE. Open circles and stars denotes LLDPE ( $\delta = 0.940 \sim 0.921$ ) and HP-LDPE ( $\delta = 0.928 \sim 0.920$ ), respectively.

Fig. 12. Frequency dependences of dynamic storage modulus  $G'(\omega)$  and loss modulus  $G''(\omega)$  for a HP-LDPE sample (A) and two LLDPE samples (B and C) at  $130^\circ\text{C}$ . The weight-average molecular weights of the samples are indicated in the figure.

#### RHEOLOGICAL PROPERTIES AND PROCESSABILITY OF LINEAR LOW DENSITY POLYETHYLENES

The processability of polymeric materials is closely related to the rheological properties in the molten state. As is well known, for example, the bubble stability in the film blowing process of LLDPE is much inferior to that of HP-LDPE with a similar melt flow index. This unstableness often makes problems in processing of the commercial polymers. But the reason has not fully understood yet. Accordingly, it is significant to investigate the rheological properties of LLDPE in the molten state and the processability of the same material.

In the present section, some comparisons of LLDPE with HP-LDPE on various rheological properties and processability parameters are tried and the origin of the difference in processability between the two types of commercial polyethylenes is discussed in terms of the rheological properties. For better comparisons, the three particular samples, one of HP-LDPE (A) and two of LLDPE (B and C) were picked up from various samples shown in Table 1. The weight-average molecular weights  $M_w$  measured in 1-chloronaphthalene at  $135^\circ\text{C}$ , the intrinsic viscosities  $[\eta]$  measured in decalin solutions at  $135^\circ\text{C}$  and the molecular weight distribution  $M_w/M_n$  for the sample A, B and C are as follows.

A (HP-LDPE) :  $M_w = 1.79 \times 10^5$ ,  $[\eta] = 1.07 \text{ dl/g}$ ,  $M_w/M_n = 6.4$

B (LLDPE) :  $M_w = 7.3 \times 10^4$ ,  $[\eta] = 1.50 \text{ dl/g}$ ,  $M_w/M_n = 4.5$

C (LLDPE) :  $M_w = 1.08 \times 10^5$ ,  $[\eta] = 1.06 \text{ dl/g}$ ,  $M_w/M_n = 7.0$

#### Dynamic viscoelastic properties

The frequency dependences of the dynamic linear viscoelastic functions, the storage shear modulus  $G'(\omega)$  and loss modulus  $G''(\omega)$ , of HP-LDPE (A) and LLDPE (B and C) measured with a Rheometrics Mechanical Spectrometer are shown in Fig. 12. The weight-average molecular weights for the samples are shown in the figure.

The frequency dependence curves of LLDPE melts are clearly different from those of HP-LDPE in the shapes. Both  $G'$  and  $G''$  curves for LLDPE are much steeper than those for HP-LDPE. This suggests that the distribution of relaxation times is broader in HP-LDPE as compared with that in LLDPE. It is well known that the broader molecular weight distribution (ref. 5) and branching of the polymer chain (ref. 6,7) make the distribution of relaxation times associated with the entanglement slippage in the polymeric liquids be broad. On account of the similarity in  $M_w/M_n$  values for the samples, Fig. 12 presumably shows the effect of branchings rather than that of molecular weight distribution, although one can not be separated exactly from the other in this figure. The same observation is possible in the flow curves, the relations between shearing stress  $\sigma$  and rate of shear  $\dot{\gamma}$ , for LLDPE and HP-LDPE samples with similar melt flow rates as shown in Fig. 13.  $\sigma$  vs.  $\dot{\gamma}$  relations are often regarded as giving a similar information to  $G'$  vs.  $\omega$  relations. Shearing stress values of LLDPE and HP-LDPE sample used here are not far off at low rates of shear, suggesting near zero-shear viscosities. However, the difference in  $\sigma$  of the two samples becomes greater with increasing rate of shear owing to the difference in slopes of the curves, which was also observed  $G''$  vs.  $\omega$  curves for the samples A and C in Fig. 12.

#### Extensional viscosity development

In connection with the polymer processing, especially with film blowing and blow moulding processes, the extensional properties of materials in the molten state are undoubtedly important. The extensional viscosity development curves for the three samples are shown in Fig. 14. The extensional stress development  $\sigma(t)$  as a function of time after applying a constant rate of strain  $\dot{\epsilon}$  was measured with Meissner-type (ref. 8) of apparatus. Then the extensional viscosity  $\eta_E^+(t) = \sigma(t)/\dot{\epsilon}$  was calculated.  $\eta_E^+$  includes not only viscous effects but also elastic ones caused by the deformation of macromolecular chains in the molten materials. The experimental results measured at three rates of strain (I, II and III) for each sample (A, B or C) are drawn as illustrated in the figure.

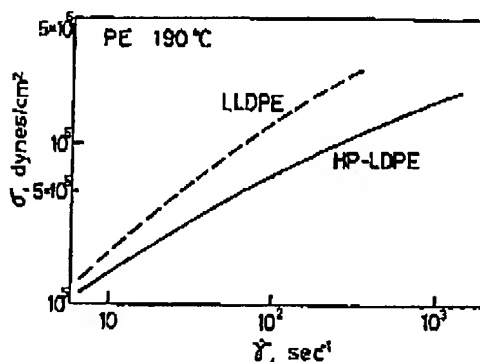


Fig. 13

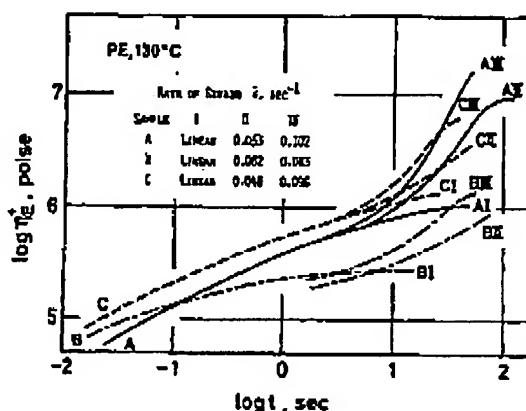


Fig. 14

Fig. 13. Shearing stress  $\sigma$  and rate of shear  $\dot{\gamma}$  relations for typical samples of LLDPE and HP-LDPE at 190°C.

Fig. 14. Extensional viscosity ( $\eta_E^+$ ) development curves for a HP-LDPE (A) and two LLDPE (B and C) at 130°C.

The "Linear" curves in the figure (I) were calculated from the linear viscoelastic functions  $G'$  and  $G''$  shown in Fig. 12 and correspond to  $\eta_E^+(t)$  when  $\dot{\epsilon} \rightarrow 0$ .

The  $\eta_E^+$  at finite  $\dot{\epsilon}$  exhibits an up-turn deviation from the "Linear" line in long time region and it becomes more remarkable with increasing  $\dot{\epsilon}$ . The curves for LLDPE samples (B and C) are similar in the shapes but different in the values; the sample C having higher molecular weight gives higher extensional viscosity.  $\eta_E^+$  curves for HP-LDPE (A) are quite different in shape from those for LLDPE. The viscosity development is much faster in short time region and the up-turn deviation from "Linear" curve is much more marked at long times. The extensional viscosity of HP-LDPE becomes the highest among the samples at the long-time end of the curves, although it was the lowest at short-time end. This behavior would also be due to the long-chain branchings of HP-LDPE.

Melt flow rate

The melt flow rate or melt flow index has been widely used as a common measure for judging the processability of commercial thermoplastic materials. In Fig. 15, the molecular weight dependence of melt flow rate, MFR, for LLDPE are compared with that for HP-LDPE. The MFR was measured under the weight of 2kg at 190°C according to ASTM D1238E. Among the data points for various samples given in Table 1, those of the particular samples A, B and C used for the measurement of rheological properties shown in Fig. 12 and 14 are marked by the sample codes.

The slope of the straight lines is -2.9, suggesting that MFR is proportional to  $M_w^{-2.9}$  for both materials. This power index 2.9 is a little lower than 3.5, the well known number for the molecular weight dependence of viscosity. The lower dependence is, of course, due to that MFR is a flow rate at fixed shearing stress in the non-Newtonian flow regime. As is

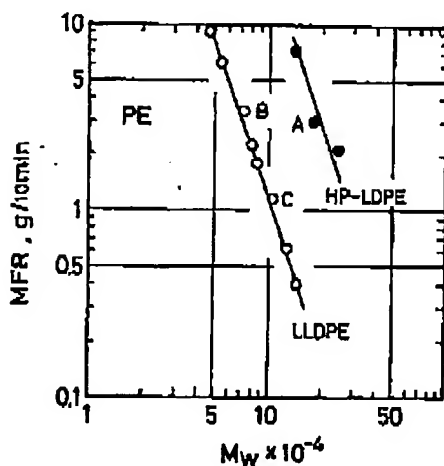


Fig. 15

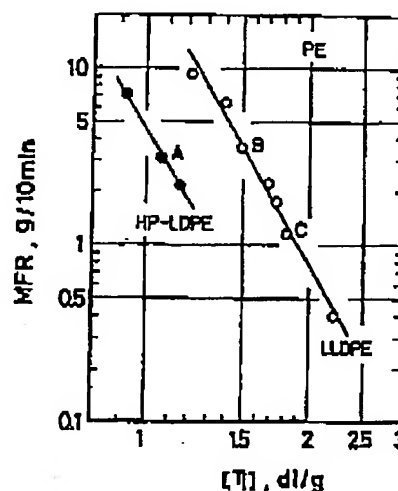


Fig. 16

Fig. 15. Melt flow rate, MFR, plotted against weight-average molecular weight  $M_w$  for HP-LDPE and LLDPE. A, B and C correspond to the samples used in Figs. 12 and 14.

Fig. 16. Melt flow rate, MFR, plotted against intrinsic viscosity  $[\eta]$  for HP-LDPE and LLDPE. A, B and C correspond to the samples used in Figs. 12 and 14.

seen from this figure, MFR value of LLDPE is more than one decade lower than that of HP-LDPE at a same molecular weight; the viscosity of LLDPE is higher than that of corresponding HP-LDPE. These difference is clearly due to the fact that the molecular dimension of LLDPE is larger than that of HP-LDPE as discussed in the previous section (solution property) and also illustrated in Fig. 4.

MFR values of the same samples as those in Fig. 15 are plotted against the intrinsic viscosity  $[\eta]$  in Fig. 16. The zero-shear viscosities  $\eta_0$  of branched polymer melts and the linear counterparts have been found to be successfully expressed (ref. 6,7,9-12) by a unique line when those are plotted against the molecular dimension and/or intrinsic viscosity.

In the case of the polyethylenes studied in this report, however, the data for HP-LDPE did not fall on the line for LLDPE as can be seen in Fig. 16. The reason would be that the LLDPE is not exactly the counterpart of the branched low density polyethylene.

Melt tension

Besides the melt flow rate, the melt tension, MT, has also widely used for the evaluation of processability of commercial polymers. The MT becomes more significant in the case that the extensional deformation and elastic properties play a important role in polymer processing such as film blowing and blow moulding. The MT data are plotted against the MFR for LLDPE and HP-LDPE samples in Fig. 17. The MT was measured under the conditions; the extrusion speed of 10mm/min, take-up speed of 12.6m/min and the die diameter of 2.1mm. Both series of polyethylene samples make the respective linear relations between  $\log MT$  and  $\log MFR$ . At a

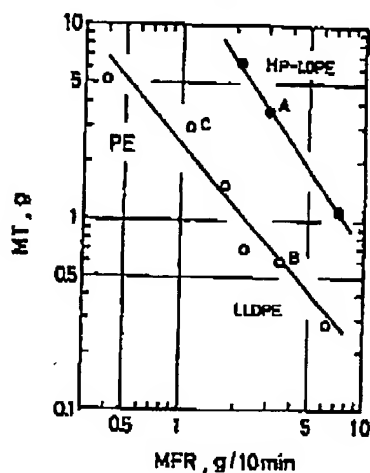


Fig. 17. Melt tension MT plotted against melt flow rate MFR for HP-LDPE and LDPE. A, B and C correspond to the samples used in Figs. 12 and 14.

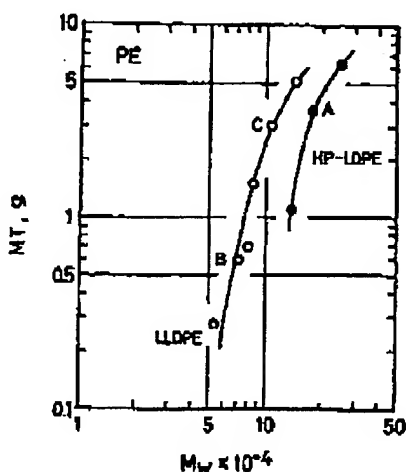


Fig. 18. Melt tension MT plotted against weight-average molecular weight  $M_w$  for HP-LDPE and LDPE. A, B and C correspond to the samples used in Figs. 12 and 14.

same value of MFR, MT of HP-LDPE is higher than that of LDPE, suggesting that the bubble stability of film blowing process is worse for LDPE as compared with that for HP-LDPE. It is also interesting that the order of MT values of the samples A, B and C indicated in this figure is exactly the same as that of the extensional viscosities in long-time region at finite rates of strain (II and III) as shown in Fig. 14. This fact suggests that the melt tensional properties and processability in film blowing are mostly governed by a nonlinear (at high rates of strain) extensional properties of the melts in a long time scale.

Figure 18 shows the molecular weight dependences of MT for the two series of polyethylenes. The MT strongly depends on molecular weight and the values of LDPE is higher than that of HP-LDPE at a same  $M_w$ , but not at same MFR as was shown in Fig. 17. It can finally be concluded that a high MFR (= a low viscosity at low rates of shear) and a high MT (= a high nonlinear extensional viscosity at long times) are necessarily required to attain a better processability of polyethylenes. These somewhat contradictory requirements would be satisfied by making the linear chains be lightly crosslinked to give a branched molecules or by blending a small amount of long branched polymer to the linear polymer.

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## 第4章 ポリプロピレン

ポリプロピレン (PP) は、従来チーグラ触媒により製造されていますが、メタロセン触媒を用いることにより、従来の触媒では製造ができなかった、新規な PP の製造ができるようになり注目されています。以下にチーグラ触媒による従来の PP (チーグラ-PP) と対比しながらメタロセン触媒による PP (メタロセン PP) について説明します。

### 4.1 ポリプロピレンの概要

#### (1) ポリプロピレンの種類

PP は、そのポリマーの立体構造上からアイソタクチックポリプロピレン (iso-PP)、シンジオタクチックポリプロピレン (synd-PP) およびアタクチックポリプロピレン (atact-PP) の3種類の異性体が存在します (第2章 2.2 節 (2) ③参照)。

従来市販されている PP は、ほとんどが iso-PP で、通常単にポリプロピレン (PP) と呼ばれています。

チーグラ触媒による iso-PP 対し、メタロセン触媒を用いることにより、従来の触媒では工業的製造ができなかった立体構造

のフローシートを図 4.2 に掲げました。

プロセス A は、第 1 世代の触媒を用い脱灰工程、脱アタクチックポリマー工程および溶媒精製工程を含む複雑なプロセスです。

プロセス B は、第 2 世代の触媒を用い脱灰工程を省略した溶媒重合プロセスです。

プロセス C は、第 2 世代の触媒を用い脱灰工程、脱アタクチックポリマー工程を簡略化したバルク重合プロセスです。

プロセス D は、第 2 世代の触媒を用い脱灰工程および脱アタクチックポリマー工程を省略した気相重合プロセスです。

現在工業化されているメタロセン PP の製造プロセスは、フィナ社と三井化学とによる synd-PP のプロセスと、エクソン・ケミカル社およびヘキスト社による iso-PP のプロセスとがあります。いずれも担持型メタロセン触媒を用い、プロピレン・モノマーを溶媒としたバルク・スラリー重合法で、反応温度は 50~70°C、圧力 20~30 kg/cm<sup>2</sup> の条件で行われているようです。

これらのプロセスは、将来的にはさらに簡素化された熱効率のよい気相重合法へ移行すべく研究開発が進められています。

### 4.3 メタロセンアイソタクチックポリプロピレンの性質と市場

メタロセン触媒による iso-PP は、チーグラ触媒による従来の iso-PP と比べて、分子量分布が狭く、熔融強度、透明性などの特徴をもっています。

4.3 メタロセンアイソタクチックポリプロピレンの性質と市場 115

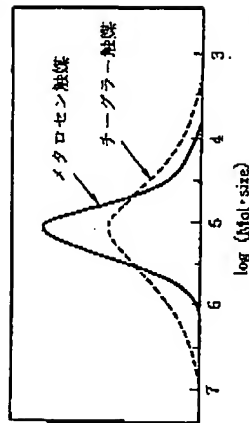


図 4.3 iso-PP の分子量分布対比 (GPC 曲線)<sup>9)</sup>

#### (1) 分子特性

##### ① 分子量分布

チーグラ-iso-PP の  $M_w/M_n$  (分子量分布の指標) が 4~10 に対し、メタロセン iso-PP は約 2 で、分子鎖の長さが揃っています (図 4.3, 表 4.4)<sup>9)</sup>。

##### ② 立体的規則性

メタロセン iso-PP は立体的規則性が高く、製造時に atact-PP の副生がほとんどありません。

#### (2) 基本・実用物性

分子量分布が狭いことと立体的規則性に優れていることに起因して、メタロセン iso-PP は下記の特徴があるポリマーです。特性を表 4.4 に示しました。

以下にチーグラ-iso-PP との相違点を示し、メタロセン iso-PP の特徴を説明します<sup>9)</sup>。

##### ① 熔融強度

熔融強度が小さい。これは、分子量分布が狭く、熔融時のすり



表 4.4 従来の iso-PP とメタロセン/iso-PP の特性値対比<sup>1)</sup>

特 性	メタロセン触媒	チーグラ触媒
MFI (230°C/5 kg)	16	15.6
T <sub>m</sub> (°C)	160.4	162
H <sub>m</sub> (J/g)	105.2	103.8
M <sub>w</sub> /M <sub>n</sub>	2.4	6.9
isotacticity (%)	98.1	95.1
結晶化度 (DSC) (%)	50.7	49.7
降伏強度 (kg/cm <sup>2</sup> )	395	370
伸び (%)	257	670
曲げ弾性 (kg/cm <sup>2</sup> )	12,600	12,500
硬 度	96	89
アイゾット衝撃強度		
23°C (kg·cm/cm)	3.9	3.1
-20°C (kg·cm/cm)	2.1	2.8
ヒカット軟化点 (°C)	153	150
密 度 (g/cm <sup>3</sup> )	0.902	0.903

速度依存性が小さいことに起因しています。この特性は、繊維の紡糸工程で糸切れを起こしにくい、フィルム加工時により薄いフィルムに速いライン速度で加工できるなどの利点があります (図 4.4)<sup>11)</sup>。

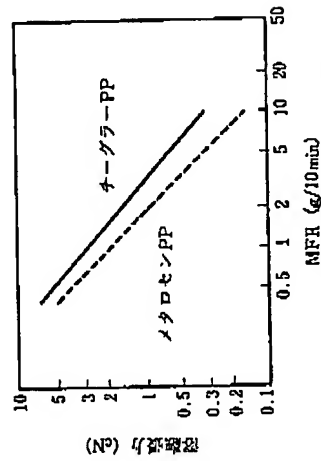
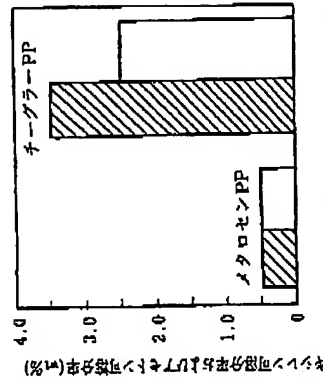
## ② 溶媒抽出量

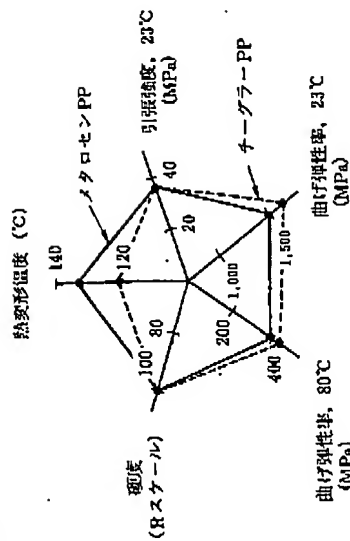
キシレンなどの溶媒による抽出量が極端に少ない。これは分子重量分布が狭く低分子量成分が少ないこと、およびアタクチック成分がほとんど副生しないことに起因しています。食品包装や食品容器用に有用で、またフィルム用ではブロッキングを起こしにくくなります (図 4.5)<sup>12)</sup>。

## ③ 耐熱性

熱変形温度が高く耐熱性に優れています (図 4.6)<sup>11)</sup>。

4.3 メタロセン/イソタクチックポリプロピレンの性質と市場 117

図 4.4 iso-PP の衝撃強さと NFR の関係対比<sup>11)</sup>図 4.5 iso-PP の溶媒抽出率の対比<sup>12)</sup>

図 4.6 同じ融点の iso-PP の射出成形品の特性対比<sup>13)</sup>表 4.5 iso-PP 2 軸延伸フィルムでの評価<sup>14)</sup>

	メタロセン PP (MFR 8)	チーグラ PP (MFR 2.5)
フィルム厚み (mm)	12	18
加工温度 (°C)	140~150	165~170
引張強度 (N/mm <sup>2</sup> )	MD 134 TD 362	120 250
引張伸び (%)	MD 210 TD 37	200~240 40~50
曇り度 (%)	0.1	2.5
光沢	116	85~90

- ④ ヒートシート性、透明性、光沢、引張強度  
2 軸延伸フィルムでの評価で、メタロセン iso-PP の方が、ヒートシート性、透明性、光沢および引張強度のいずれの特性においても優れています (表 4.5)<sup>14)</sup>。

## 4.4 シンジオタクチックポリプロピレンの性質と市場 119

## (3) マーケティング状況

メタロセン iso-PP は下記の用途を中心に検討がなされています。

- ① 溶融張力が小さいことを活かしたスパンボンブ不織布用やフィルム用
- ② 耐熱性に優れていることを活かした射出成形用
- ③ 溶媒抽出量が少ないことを活かした食品包装用フィルムや食品容器用
- ④ ヒートシート性、透明性を活かしたフィルム用

## 4.4 シンジオタクチックポリプロピレンの性質と市場

synd-PP は、耐衝撃性、透明性および耐放射線性で特徴ある特性を持っています。以下にチーグラ-iso-PP と対比しながら特徴を説明します。

## (1) 分子特性

synd-PP の結晶構造は iso-PP と異なって複雑で、DSC (示差走査熱量分析) による分析で複数の融解ピークが観測されます (図 4.7)<sup>9)</sup>。

このちがいににより次項で記す特徴が得られます。

## (2) 基本・実用物性

synd-PP の特徴は、ほぼ次の通りです。

- ① 曲げ剛性、曲げ強度、耐衝撃性、加工性  
軟質であり可塑性なしで PVC 用カレンダーで加工が可能で、

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## Chapter 4 Polypropylene

Polypropylenes (PP) have been conventionally produced with a Ziegler catalyst. Yet, with the use of a metallocene catalyst, a novel PP which has not been obtained with the conventional catalysts can now be obtained and thus is attracting attention. In the following, the illustration is provided of a PP obtained with the metallocene catalyst (metallocene PP) compared with a conventional PP obtained with the Ziegler catalyst (Ziegler PP).

### 4.1 Outline of Polypropylene

#### (1) Types of Polypropylenes

With regard to PP, there are three types of isomers in terms of the stereoregularity of the polymer: isotactic polypropylene (iso-PP), syndiotactic polypropylene (synd-PP) and atactic polypropylene (atact-PP) (See Chapter 2, Section 2:2(2)③).

Conventional and commercial PP are mostly iso-PP and are usually called, simply, polypropylenes (PP).

#### 4.3 Nature and Market of Metallocene Isotactic Polypropylene

The iso-PP obtained with the metallocene catalyst has narrower molecular weight distribution and also has properties such as melt tension and transparency, compared with the conventional iso-PP obtained with the Ziegler catalyst.

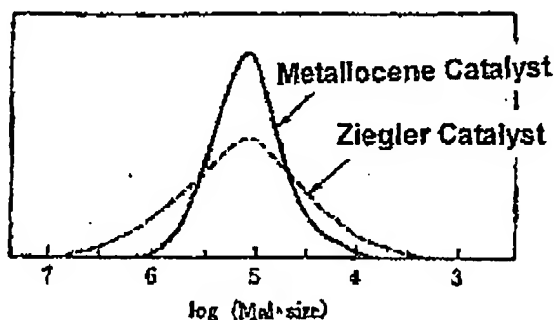


Fig. 4.3 Comparison of Molecular weight distribution of iso-PP (GPC curve)

##### (1) Molecule Property

###### ① Molecular weight distribution

The Ziegler-iso-PP has 4 to 10 of Mw/Mn (an index of molecular weight distribution) whereas the metallocene iso-PP has approximately 2 of Mw/Mn and has a uniform length of molecular chain (Fig. 4.3 and Table 4.4).

###### ② Stereoregularity

The metallocene iso-PP has a high stereoregularity and its production hardly by-produces atact-PP.